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The Role of Dyadic Coordination in Organizing Visual Attention in 5-Month-Old Infants

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In human infants, the ability to share attention with others is facilitated by increases in attentional selectivity and focus. Differences in early attention have been associated with socio-cognitive outcomes including language, yet the social mechanisms of attention organization in early infancy have only recently been considered. Here, we examined how social coordination between 5-month-old infants and caregivers relate to differences in infant attention, including looking preferences, span, and reactivity to caregivers' social cues. Using a naturalistic play paradigm, we found that 5-month-olds who received a high ratio of *sensitive* (jointly focused) contingent responses showed strong preferences for objects with which their caregivers were manually engaged. In contrast, infants whose caregivers exhibited high ratios of *redirection* (attempts to shift focus) showed no preferences for caregivers' held objects. Such differences have implications for recent models of cognitive development, which rely on early looking preferences for adults' manually engaged objects as a pathway toward joint attention and word learning. Further, sensitivity and redirectiveness predicted infant attention even in reaction to caregiver responses that were *non-referential* (neither sensitive nor redirective). In response to non-referentials, infants of highly sensitive caregivers oriented less frequently than infants of highly redirective caregivers, who showed increased distractibility. Our results suggest that specific dyadic exchanges predict infant attention differences toward broader social cues, which may have consequences for social-cognitive outcomes.

Across early development, human infants are immersed in an environment in which various opportunities for growth and learning are embedded in the structure of social behavior (Goldstein & Schwade, 2009; Goldstein et al., 2010; Yu & Smith, 2012). As infants explore their surroundings, caregivers and other adults provide diverse forms of social feedback to their behaviors (de Barbaro, Johnson, & Deák, 2013; Crown, Feldstein, Jasnow, Beebe, & Jaffe, 2002; Gros-Louis, West, Goldstein, & King, 2006). Such feedback can provide infants with vital information about the social and physical environments, as well as the grammatical and phonological structure of their

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surrounding language (Goldstein & Schwade, 2008; Goldstein, Schwade, Briesch, & Syal, 2010; Wu, Gopnik, Richardson, & Kirkham, 2011).

In order to gain access to the information available from social interactions, infants must develop the ability to control their attention, so that they can flexibly maintain focus on the environmental and social cues relevant to their current needs and goals. Additionally, infants must select and distinguish which cues are in fact relevant in the midst of potential distractions. Such skills converge over time and experience to allow infants to engage in *attention sharing* with adults and other social partners (Deák, Triesch, Krasno, de Barbaro, & Robledo, 2013). Along with gaze following, attention sharing is considered a critical precursor to more triadic and deliberate joint attention, in which children and adults reciprocally direct and share attention on a third point of reference (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998). Accordingly, early attention sharing skills among infants and caregivers have been related to immediate learning and long-term communicative outcomes (Mundy et al., 2007; Yu & Smith, 2012), whereas difficulties in early attentional control, selection, and sharing have been implicated in later neurodevelopmental diagnoses (Dawson et al., 2004; Elsabbagh et al., 2013). While such findings emphasize the importance of understanding the processes underlying early attentional abilities, there are still many unknowns regarding how infants learn to control, direct, and share attention across early experience, including which factors are most influential in determining individual differences.

To explain how infants learn to control and share attention, previous research has focused on identifying intrinsic properties of human adults that may explain emerging attentional abilities as well as variation across individuals. For instance, some findings have suggested that from birth, infants are biased to visually attend to socially relevant stimuli, including others' faces and eyes (Morton & Johnson, 1991). Subsequent psychologists have interpreted these biases as reflecting a specialized and inherent attunement to social cues regardless of postnatal dyadic experience (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000), proposing that individual differences in attention sharing arise via deficits in these specialized systems (Senju, Yaguchi, Tojo, & Hasegawa, 2003). However, more recent work in naturalistic environments suggests that skills including shared attention and gaze following arise gradually and are incrementally refined and improved, presumably through experience and learning (e.g., Corkum & Moore, 1998; Deák, Krasno, Triesch, Lewis, & Sepeta, 2014; Yu & Smith, 2016; also see Deák et al., 2013 for review). Infants' apparent interest in faces and eyes has also been shown to vary with development when assessed in more ecologically relevant settings, as new motor skills and postures afford different vantage points from which to explore other objects and areas of potential appeal (Deák et al., 2014; Fausey, Jayaraman, & Smith, 2016; Kretch, Franchak, & Adolph, 2014). Such findings indicate that the development of attention sharing may be more dependent on experience than previously thought and that early visual biases towards others' faces are not sufficient to explain developmental change.

Based on recent findings, current theories on the emergence of attention sharing and gaze following have proposed that these skills may be shaped by infants' early interactions with their caregivers. Specifically, infants may learn to share and follow gaze through dyadic experiences that allow them to associate their caregivers' direction of gaze with predictive value (Gottlieb, Oudeyer, Lopes, & Baranes, 2013; Oudeyer & Smith, 2016), as well as with locations of objects and sights that infants find interesting and rewarding (Moore & Corkum, 1994; Triesch, Teuscher, Deák, & Carlson, 2006).

Such theories require caregivers' social cues to have a strong *social signal-to-noise* ratio (SSNR), meaning that the number of caregiver visual cues that create predictable events around an infant's focus of attention should be greater than the number of cues that are non-predictive or irrelevant to infants' attention. To explore whether such predictive structure is present in caregivers' cues, subsequent studies have characterized infants' and caregivers' visual behavior during home-based and semi-naturalistic dyadic interactions (Deák et al., 2014; Yu & Smith, 2013). Both paradigms suggest that infants across the first year often prefer attending to objects that caregivers are manually manipulating during caregiver–object play (though see Jayaraman, Fausey, & Smith, 2015 for a broader analysis of infant looking across various dyadic activities), and that caregivers often also attend to these objects. Subsequently, during the rare moments in which infants do attend to caregivers' faces, caregivers are often shifting gaze to the objects that infants strongly prefer, namely the objects they are touching or holding (Deák et al., 2014). Such dyadic patterns imply that it is possible for infants to learn to associate caregivers' eye gaze with rewarding sights, as caregivers' gaze cues often align with the objects that their infants prefer. Furthermore, infants' apparent looking preferences for handled objects may be a crucial requisite for learning social cues, given that caregivers' eye gaze and manual focus tend to overlap reliably (Yu & Smith, 2013).

Building on the presence of reliable structure in caregivers' responses to infant looking, new work has begun to explore how caregivers' social cues may consequently influence the development of broader abilities supporting joint attention, such as attentional maintenance and word learning. For instance, when parents share visual attention with objects that their 12-month-olds focus on, infants extend their gaze duration on those objects even after their parents stop attending to them (Yu & Smith, 2016). Additionally, when parents verbally label objects that their toddlers are holding and visually isolating, toddlers are more likely to learn these object labels and subsequently attend to these objects when prompted by a new adult (Yu & Smith, 2012). These results indicate that parents' social cues may help to strengthen older infants' and toddlers' own attentional maintenance and cue following, which may have implications for future joint attention outcomes.

Given the importance of caregivers' social feedback for the development of skills supporting joint attention, does variability in caregivers' social coordination with their infants help to predict or explain individual differences in such abilities? Social coordination is often multimodal, incorporating verbal and visual behavior in organizing the timing and content of parental feedback. The timing of such coordination is critical. Many studies have found that caregivers' verbal responses and other behaviors are more likely to influence infant attention and learning when they are coordinated reliably and promptly with (i.e., are *contingent* on) infants' behaviors. The efficacy of caregiver contingency has been demonstrated especially in studies of word–object learning (Goldstein et al., 2010) and in studies of general attentional organization (Dunham, Dunham, Hurshman, & Alexander, 1989).

Within the repertoire of contingent responses, however, the physical and semantic alignment of caregivers' contingent behaviors with infants' focus has also been associated with differences in learning and attention (Landry, Smith, & Swank, 2006; McGillion et al., 2013). Developmental psychologists have used the term *sensitivity* to describe a vast array of both stable and developmentally variable caregiver behaviors that may indicate attunement to infants' attentional or emotional state (e.g., Ainsworth, 1979; Bigelow et al., 2010; Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008; Mesman, 2010). On a microstructural level, sensitivity more specifically denotes moment-by-moment instances in which caregivers' contingent responses follow and are congruent with infants' visual focus of attention. When defined in this framework, contingent verbal sensitivity during infancy positively predicts early vocabulary and language comprehension (Baumwell, Tamis-LeMonda, & Bornstein, 1997; Tomasello & Farrar, 1986), and more recent experimental work has suggested increased social attentional engagement and improved social learning among infants interacting with verbally sensitive adults (Miller & Gros-Louis, 2016).

In contrast to sensitive responses, another type of contingent behavior typically considered divergent from sensitivity is *redirectiveness*. Redirectiveness describes caregiver behaviors that attempt to shift or distract infants from their current object of focus, implying a lack of congruency between the caregiver's focus and that of the infant (e.g., Baumwell et al., 1997; Tomasello & Farrar, 1986). At the microbehavioral level, redirectiveness among social partners and caregivers has been linked to increased moment-by-moment distractibility in older infants, as well as lower vocabulary size at later ages (Miller, Ables, King, & West, 2009; Miller & Gros-Louis, 2013; Tomasello & Farrar, 1986; though see Shimpi & Huttenlocher, 2007). Taken together, the findings on contingency, sensitivity, and redirectiveness support the notion that both the form and timing of caregivers' interactions with infants may influence dyadic coordination, and that contingent sensitivity and redirectiveness in particular may be critical when considering early social influences on infant attention organization.

In this study, we investigated how differences in caregivers' relative levels of contingent sensitivity and redirectiveness might relate to individual differences in infants' visual attention in social contexts. In particular, we explored how different response structures relate to (1) differences in infants' looking preferences to caregiver-handled objects; (2) infants' general distractibility; and (3) infants' moment-by-moment reactions to caregivers' contingent responses.

Do differences in caregiver sensitivity/redirectiveness predict differences in infants' social looking preferences?

Regarding looking preferences, recent joint attention models support a strong role for early looking preferences toward adults' manually engaged objects as a pathway towards joint attention (Deák et al., 2013, 2014; Yu & Smith, 2013). Such models beg the question: Do differences in caregiver sensitivity and redirectiveness promote or discourage infants' visual preference for caregiver-handled objects? We predicted that if caregivers' actions are more sensitive on average, then infants should show strong preferences for their caregivers' objects, as they are more likely to have learned that their caregivers are often engaged with objects that they themselves find visually rewarding. In contrast, if caregivers' actions are more redirective on average (i.e., incongruent with infants' object focus), then infants may learn that their caregivers are not likely to be engaged with the objects that they themselves are demonstrating an interest in. Subsequently, we predicted that infants of highly redirective caregivers should not show any clear preference for looking at caregiver-manipulated vs. unengaged (static) objects.

Do differences in caregiver sensitivity/redirectiveness predict differences in infants' general attention span?

Another early factor proposed by Deák et al. (2013) to be important for attention sharing is the degree to which infants *exploit* or maintain attention on their current task or object of gaze, vs. *exploring* and seeking out other potentially rewarding stimuli (Aston-Jones & Cohen, 2005). Previous experimental findings have related redirective social interactions to infant distractibility (Miller et al., 2009), while other findings have related parents' visual sensitivity with increases in older infants' attention durations (Yu & Smith, 2016). Accordingly, we expected high levels of caregiver sensitivity to encourage increased *exploitation* and attentional maintenance on the part of infants. In contrast, we expected high levels of caregiver redirectiveness to cause increased arousal on the part of infants, in turn corresponding to higher rates of gaze shifting (*exploration*) as well as a greater tendency to seek out new salient objects when shifting gaze.

Do differences in caregiver sensitivity/redirectiveness predict differences in infants' attentional reactivity toward social cues specifically?

One final skill important for attention sharing and overall communicative development is the ability to differentiate which social behaviors are relevant to attend and respond to, and which are not (Kuchirko, Tafuro, & Tamis Lemonda, 2018). Considering how caregiver sensitivity and redirectiveness might facilitate or hinder infants' ability to distinguish relevant social cues, we expected high caregiver sensitivity to correspond with more refined and appropriate social attentional attunement on the part of infants (Kuchirko et al., 2018), and high redirectiveness to correspond with less selectivity and increased distractibility in response to caregivers' behaviors. To examine the effects of caregiver sensitivity and redirectiveness on infants' attention toward broader social cues, we assessed infants' reactions to their caregivers' contingent responses overall as well as specifically to responses that were *non-referential*, that is, not related to any object or area of focus in the infant's immediate environment. Because non-referentials are not intended to direct infants' attention to a particular location, we predicted that infants' reactions to non-referentials may illuminate potential attentional biases and habits learned from the overall SSNR (predictable structure) of their caregivers' behaviors. Specifically, we hypothesized that infants of relatively sensitive caregivers should not be distracted by non-referentials, as they may have learned that their caregivers' behaviors are generally congruent with infants' attentional focus. In contrast, infants of relatively redirective caregivers may be more distracted by non-referentials, as they have associated their caregivers' behavior with a change in focus. As redirections often elicit attention to new objects, we also hypothesized that infants of highly redirective caregivers would perhaps shift intuitively toward objects in response to non-referentials also, whereas infants of highly sensitive caregivers would not have an obligatory pattern of focus when reacting to non-referentials.

To explore our primary questions, we used *micro*level methods (for a discussion of macro- vs. micro-approaches, see Hsu & Fogel, 2003) to characterize 5-month-olds' visual attention patterns during dyadic social interactions. We focused on 5-month-olds because social learning and attention preferences are already robust at this age (Deák et al., 2014; Goldstein, Schwade, & Bornstein, 2009), and individual differences in attentional patterns (i.e., habituation) are detectable by this age as well (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991). However, the effects of caregiver sensitivity and redirectiveness on attention in infants younger than 6 months are currently less known. This study aimed to predict how early differences in social feedback (particularly, high SSNRs of caregiver sensitivity or redirectiveness) might influence infant gaze behaviors that potentially contribute to later attention and learning differences. Overall, we hypothesized that high caregiver sensitivity should predict more typical infant gaze preferences and social attunement as found in prior observational work, while high caregiver redirectiveness should correspond to less social attunement, higher distractibility, and lack of a clear preference for attending to objects that caregivers are manipulating.

METHOD

Participants

To analyze caregivers' social behavior, data were derived from a sample of convenience consisting of 67 caregivers and their 5-month-old infants (30 female, 37 male; mean age 5 months, 10 days [range 147–183 days]). These dyads were part of a larger ongoing longitudinal study assessing relations between infant vocal learning at 5 months and later language ability, and were recruited via birth announcements, flyers, and community outreach events in Ithaca, New York. Of the 67 caregivers evaluated, 65 completed our demographic survey. Caregivers' mean ages were 32.6 years (mother; range 23–47 years) and 34.1 years (partner/spouse; range 24–61 years). Approximately 86.4% of respondents were White, non-Hispanic; the remaining 13.6% identified as African American (1.7%), Chinese (3.4%), Latino/South American (3.4%), Puerto Rican (1.7%), Pakistani (1.7%), or Biracial (1.7%). Additionally, all who responded had completed at least some college at the time of the study, with the majority (80.3%) having obtained a bachelor's degree or higher.

For infant attention analyses, we selected infants whose caregivers were classified as exhibiting the highest SSNRs of either sensitivity (HS group) or redirectiveness (HR group) in the overall sample (Figure 2c; for full description of selection criteria, see Coding and Dyad Selection below). The final sample of infants whose caregivers matched this criterion was 17 (7 HS, 10 HR). Infants in each group had no known health issues or developmental diagnoses at the time of the study, and the groups did not significantly differ in age (mean HS = 159 days; mean HR = 161 days), sex distribution (in HS = 3 females of 7, in HR = 5 females of 10), number of siblings (mean HS < 1 sibling, mean HR < 1 sibling), parents' ethnicity (# White non-Hispanic in HS = 6 of 7, in HR = 8 of 10), or parents' education level (# parents with a bachelor's degree or higher in HS = 5 of 7, in HR = 8 of 10; *p*s > .36 for all).

Materials

For the free-play activity, infants and their caregivers were recorded in a 12 × 18 ft. playroom using three wall-mounted Sony® DCR-TRV900 camcorders, which were positioned to capture multiple viewing angles. A toy box containing a standard set of age-appropriate toys was made available for infants' and caregivers' use, along with a circular play mat placed in the center of the room. The presence of the toys and the spaciousness of the play area were designed to encourage free range of movement and interaction between the infant and caregiver in an unstructured and semi-naturalistic context. Additionally, caregivers wore a wireless microphone (Telex FMR 1000) to capture their verbal prompts and responses, while infants wore a pair of customized overalls outfitted with a concealed wireless microphone and transmitter (Telex FMR 500) to record their vocalizations during the play session.

Procedure

This study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Institutional Review Board at Cornell University. After obtaining informed consent, a trained researcher video-recorded infants and their caregivers as they engaged in a short set of tasks designed to assess both social and non-social abilities underlying vocal learning at age 5 months. Dyads participated in a 15-min unstructured play session in our laboratory playroom. For this task, caregivers were instructed to play with their infant as they would at home with the toys provided and were given no additional prompts. However, caregivers and infants were allowed to take breaks and resume play if the infant became fussy throughout the interaction. Additionally, the first 5 min of the interaction served as a warm-up period for the caregivers and infants, to allow them to become accustomed to the room, toys, and cameras. Thus, all subsequent analyses were restricted to the last ten minutes. The order in which infants and caregivers completed the play session relative to other activities within the broader study was randomized and counterbalanced, and infants received a T-shirt, bib, or toy prize for participation.

Coding and dyad selection

Following video recording, one trained coder blind to the current study questions reviewed the free-play sessions and identified all infant vocalizations and sustained fixations (i.e., looks lasting longer than 0.5 sec; this criterion is in accord with "meaningful fixation" thresholds used in other infant literature (e.g., Fernald, Zangl, Portillo, & Marchman, 2008; de Barbaro, Chiba, & Deák, 2011), while also incorporating considerations of adults' typical fixation durations and the minimum event durations needed to notice an infant behavior (Wass & Smith, 2014)). The coder then identified caregiver responses that occurred *contingently* on (i.e., within 2 sec of; Gros-Louis et al., 2006; McGillion et al., 2013) these infant behaviors. Caregivers' contingent responses were labeled using one of the following categories: s*ensitive response* (a response congruent in space and time with the infant's own focus of attention following a long look or vocalization by the infant); *redirective response* (an active attempt to direct the infant's attention away from his or her current focus in response to a long look or vocalization); and *non-referentials* (imitations, narrative responses unrelated to infants' focus, non-sequiturs, or affirmations; laughs, exclamations, and inspirations were also included within this category). More detailed descriptions and examples of each response classification are shown in Table 1.[1]

[1]Additional details on the coding schemes, including full coding manuals, are available on Open Science Framework (OSF) at https://osf.io/qfgez/

TABLE 1
Description of Caregiver Contingent Response Types and Examples

Response Type	*Description*	*Verbal examples*	*Non-verbal/multimodal examples*
Sensitive responses	Response congruent in space and time with the infant's own focus of attention	Infant looks and/or babbles at toy, then caregiver labels same toy within 2 sec; infant babbles or focuses on caregiver, then caregiver says "hi"/acknowledges look verbally within 2 sec	Infant looks and/or babbles at toy, then caregiver picks up same toy (or picks up toy and labels) with 2 sec; infant looks/babbles at caregiver, and caregiver plays dyadic game ("peekaboo" with hands covering face, etc.) within 2 sec
		Special sensitive cases (verbal and non-verbal/multimodal): *Social referencing*: infant looks at toy, then looks at caregiver; response is sensitive if caregiver engages with the same toy that the infant had looked at directly prior *Undirected looking*: caregiver's response is *sensitive* if (s)he attempts to engage infant with a toy or herself when infant is looking undirected	
Redirective responses	Attempt to direct the infant's attention away from his or her current focus	Infant looks and/or babbles at toy, but caregiver says "look at me!", "look at this other toy!", etc. Infant looks and/or babbles at caregiver, and caregiver verbally instructs infant to look at a toy that infant had not just been engaged with	Infant looks and/or babbles at toy, but caregiver picks up a different toy in response. Infant looks/babbles at caregiver, and caregiver directs to an object that the infant had *not* been looking at directly prior
Non-referential (other) responses	Statements or actions not related directly to the infant's current focus of attention	Conversational placeholders (e.g., gasps, aspirations, laughs); narrating the state of the infant but not what (s)he is focused on (e.g., "good job!" after an infant action; "look at you go!" when infant is moving, etc.); non-sequiturs (statements not related to anything in the immediate area or anything specific the baby is doing, e.g., "what's for dinner tonight?"); vocal imitations of infant babbles	Physical imitations of infant actions (for instance, mom crawls next to infant as infant is crawling; mom claps hands after infant claps hands; etc.)

After caregivers' responses had been quantified, researchers calculated the proportions of sensitive and redirective behaviors displayed by each caregiver relative to their total responses (Figure 2a–c). The distributions of these proportions allowed us to identify caregivers who exhibited the highest social signal-to-noise ratios of either sensitivity or redirectiveness in the sample. *Highest sensitive/low redirective* (HS) caregivers fell into the top 25% of sensitivity and the bottom 50% of redirectiveness. *Highest redirective/low sensitive* (HR) caregivers fell into the top 25% of redirectiveness and the bottom 50% of sensitivity. The final sample consisted of 17 dyads (HS = 7, HR = 10).

Once infants had been targeted for analysis, the first author (who was blind to infants' caregiver group assignments) coded both long and short bouts of infant visual attention behaviors, using procedures modified from Deák et al. (2014) and Miller et al. (2009). Coding was completed using ELAN video annotation software created by the Language Archive at the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands (https://tla.mpi.nl/tools/tla-tools/elan/; Sloetjes & Wittenburg, 2008). Infant visual fixations and shifts of attention were indexed frame-by-frame at 30 frames per second. Infants' focus of looking was classified under one of the following categories (Figure 1): *objects* (during periods in which caregivers were manipulating objects, this category was subclassified as *caregiver-engaged* or *static*, to capture moments in which infants were and were not attending to the caregivers' handled object), *caregiver* (including the caregiver's face, upper body, and hands), *other/undirected areas* (this included the walls, ceiling, and floor of the playroom, as well as the infant's own body and the caregiver's lower body), and *uncodable time,* which was excluded during analyses (this included moments in which infants' eyes or areas of focus were out-of-view of the current camera view, as well as instances in which infants' eyes were closed). To classify infants' object looking as *caregiver-engaged* or *static*, the first author additionally identified all instances in which caregivers touched, manipulated, or held objects during the interaction, regardless of the time window between such actions and infants' preceding actions. Infants were characterized as looking at *caregiver-engaged* objects during frames in which they were fixated on the object(s) that the caregiver was manipulating, while *static object* looking occurred during frames in which infants were fixated on a different object than the one that the caregiver was manipulating.

Additionally, when assessing infant gaze shifting during short (<2 sec) caregiver handling bouts (which often occurred in rapid succession), we applied a 2-sec contingency window to capture subsequent infant attention changes. As similar "bursts" of caregiver interactive behavior toward infants have been grouped using a 2-sec criterion in previous studies (see Kaye & Fogel, 1980), we considered object-handling bouts <2 sec apart as continuous when examining whether infant attentional reorientations were occurring. Additionally, given that infants' average shift rate was approximately one shift every 2 sec (mean(*SD*) = 30.45(10.83) shifts/min; median = 33.56 shifts/min), a 2-sec contingency window seemed suitable to account for infant shifts that might occur in reaction to even the briefest of caregivers' object holds (see Keller, Lohaus, Völker, Cappenberg, & Chasiotis, 1999 for a discussion of the use of different contingency windows in examining dyadic coordination).

To assess reliability, two separate coders blind to both the infants' caregiver group assignment and to the overall hypotheses of the study recoded a randomly selected subset of 25% of every video. One coder coded caregiver object handling and infant looking preferences, while the other coded infants' fine-grained attention shifts.

Figure 1 Examples of free-play setup and infant looking. (a) Illustrates looks to caregiver-engaged (held or manipulated) objects, while (b) depicts infant looks to caregiver-unengaged ("static") objects. (c) Shows infant looking towards the caregiver (including caregivers' hands), and (d) illustrates looks to undirected or other areas, such as the infant's own body. More examples and information on the coding scheme are available on Open Science Framework at https://osf.io/qfgez/.

Absolute intraclass correlation coefficients for infant attention variables ranged from strong to excellent (*single-measures*: .76–.99; Table S1), while the average absolute ICC value for caregiver object handling was .99, indicating nearly perfect agreement.

Data analyses

Our primary analyses comprised three main objectives: (1) to characterize 5-month-olds' looking preferences during naturalistic social interactions, and to investigate whether caregivers' SSNRs of sensitivity and redirectiveness relate to differences in these preferences; (2) to compare 5-month-olds' attention dynamics (*exploitation* vs. *exploration*, measured by infants' gaze shift frequency) relative to their caregivers' SSNRs of sensitivity and redirectiveness; (3) and to investigate whether caregivers' SSNRs of sensitivity and redirectiveness predict differences in infants' inclinations to shift visual attention specifically in reaction to caregivers' contingent responses. We also assessed whether increased sensitivity or redirectiveness covary with other aspects of caregiver behavior that might influence attention, such as overall activity levels and object handling.

We evaluated infants' looking preferences by comparing infants' proportional looking times at all possible regions of interest (see *Coding* above for description), while infant attention dynamics were assessed by obtaining indices of each infant's attention shifting during free play. To do this, we divided the total number of attention shifting events for each infant by the total minutes of codable time in their individual play sessions. We calculated separate indices of attention shifting during caregiver object handling vs. non-handling periods. Finally, we assessed the degree to which caregivers' contingent responses broadly elicited contingent infant attention shifts, by calculating the proportion of caregivers' behaviors that elicited a shift within 2 sec (Gros-Louis et al., 2006).

We also assessed the specific impact of redirective and non-referential caregiver behavior on infant attention. Redirection success was measured by the proportions of caregivers' redirections in which the caregiver effectively shifted the infant's focus to a new object. Additionally, we calculated infants' average latencies to attend to the new object, as we viewed this as an additional measure of infants' attunement to caregivers' social cues. We also examined infant shifting in response to caregivers' non-referential responses, to identify attentional biases evidenced by shifting after receiving open-ended social feedback. After calculating each variable for individual dyads, values were averaged at the level of caregiver group (HS and HR), and groups were compared using ANOVA and *t*-test analyses.

RESULTS

Caregiver response structure

Broader caregiver sample

Figure 2a–c details the overall proportions of contingent sensitive and redirective responses observed in our broader caregiver sample ($n = 67$). Caregivers' SSNRs of sensitivity were approximately normally distributed (Figure 2a; mean SSNR = 41.9%, K-S test = 0.06, $p > .20$), with values ranging from 20.5% to 68.9% of all responses. Compared to this range, caregivers exhibited relatively lower SSNRs of redirective responses, with values ranging from 0.0% to 36.6% of all responses (Figure 2b). Caregivers' redirective responses were also normally distributed (K-S test = 0.09, $p > .20$).

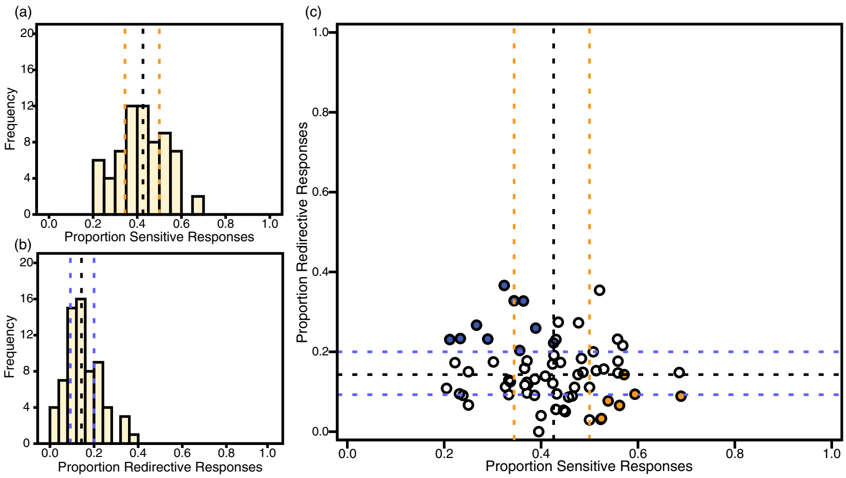

Figure 2 SSNRs of contingent sensitive and redirective responses exhibited by caregivers during free play (calculated as proportions of total contingent responses). (a) Displays the proportions of sensitive responses (relative to all contingent responses) in the sample, with dotted lines denoting distributional cutoffs at 25%, 50%, and 75%, respectively. (b) Depicts the relative proportional distributions of redirective responses. In (c), the proportions of sensitive and redirective responses observed in each caregiver are displayed relative to one another. Caregivers whose infants were selected for attention analyses are highlighted in orange (HS caregivers) and blue (HR caregivers). Dotted orange lines represent the 25% (left) and 75% (right) cutoff values for sensitive responses, while dotted blue lines represent the 25% (bottom) and 75% (top) cutoff values for redirective responses. Dotted black lines represent the middle (50%) cutoff values for both distributions.

Figure 2c plots each caregiver's individual proportions of sensitivity and redirectiveness relative to one another. There was no significant correlation between caregivers' relative levels of sensitive and redirective responding in the broader sample ($r(65) = -0.14$, $p = .25$). However, both sensitivity and redirectiveness were significantly negatively correlated with the proportions of non-referential responses (sensitivity & non-referentials: $r(65) = -0.78$, $p < .001$; redirectiveness and non-referentials: $r(65) = -0.51$, $p < .001$; [Figure S1]). As all three response categories (sensitive, redirective, and non-referential) are mutually exclusive, the negative correlations between non-referential responses and the other response types are not surprising, particularly given the lack of correlation between levels of sensitive and redirective responding.

Targeted caregiver groups

As described in Methods, based on the proportions of sensitivity and redirectiveness observed in our sample, we selected infants of caregivers whose response proportions fell within the top 25% of sensitivity and bottom 50% of redirectiveness (HS), or within the top 25% of redirectiveness and bottom 50% of sensitivity (HR; Figure 2c). While only a small sample of caregivers fell into these groups, these cutoffs allowed us to assess caregivers with the highest SSNRs of sensitivity and redirectiveness possible. At the group level, caregivers exhibited significantly disparate proportions of sensitivity and redirectiveness (sensitivity: HS mean = 57.17%, HR mean = 32.04%, $t(15) = 7.88$, $p < .01$; redirectiveness: HS mean = 7.60%, HR mean = 26.69%, $t(15) = -7.92$, $p < .01$).

To evaluate whether HS and HR caregivers displayed differences in other relevant behaviors that might affect infant attention, such as general activity levels throughout the session, we also assessed caregivers' object handling and contingent responding. HS and HR caregivers did not significantly differ in their raw time spent engaged with objects (mean HS = 166.05 sec, mean HR = 211.70 sec, $t(15) = -0.96$, $p = .35$), or in their relative time engaging with objects during infants' codable looking periods (mean HS = 27.92% of codable time, mean HR = 36.55% of codable time; $t(15) = -1.06$, $p = .31$). Additionally, caregivers did not differ in their raw number of contingent responses (mean HS = 77.29 responses, mean HR = 64.00 responses, $t(7.03) = 0.97$ $p = .37$) or in their rate of contingent responses across the session (assessed by dividing the raw number of contingent responses by total codable time: mean HS = 8.78 responses/min, mean HR = 8.08 responses/min, $t(15) = 0.43$, $p = .68$). The contingent responses of HS and HR caregivers, when examined by modality (vocal, behavioral, combination of vocal and behavioral), also did not differ across groups (Table S2). We next examined whether HS and HR caregivers differed in their speed of responding to infant behavior. Latencies of HS and HR caregivers' first contingent responses within infants' looks did not significantly differ (mean(*SD*) HS = 1.80 (0.57) sec, mean(*SD*) HR = 1.46 (0.28) sec, $t(8.05) = 1.45$, $p = .18$).

Regarding codable time, all dyads had at least 6.5 minutes of codable time (minimum = 392.89 sec), with all but one dyad having greater than 7 min of codable time. These durations of codable time are in line with durations reported in previous studies assessing caregiver–infant interaction and attention (Deák et al., 2014; Hsu & Fogel, 2003; Miller et al., 2009; Wan et al., 2012). Between groups, HS and HR dyads did not differ significantly in their raw uncodable time when caregivers were engaged with objects (mean(*SD*) uncodable HS = 17.37 (21.41) sec, mean(*SD*) HR = 37.33 (28.06) sec, $t(15) = -1.58$, $p = .14$). Dyads also did not differ in their proportions of uncodable time relative to total engaged time (mean(*SD*) uncodable HS = 10.52% (7.19%) of total engaged time; mean(*SD*) HR = 16.85% (9.12%) of total engaged time; $t(15) = -1.53$, $p = .15$). However, when caregivers were not engaged, HR dyads had more uncodable time on average than HS dyads (raw uncodable HS = 35.98 (21.82) sec, raw uncodable HR = 72.95 (40.84) sec, $t(15) = -2.18$, $p = .046$; proportion uncodable HS = 8.68% (5.52%) of unengaged time, proportion uncodable HR = 19.61% (9.10%) of unengaged time, $t(15) = -2.82$, $p = .013$). To account for differences in codable time across dyads when assessing infant attention, we normalized infant looking times and overall attention shifting by calculating these variables as proportions and rates relative to each dyad's codable time (see Data analyses above). Additionally, when assessing infant looking preferences during caregiver unengaged periods, we reran our analysis to include infants' uncodable time during these periods as a covariate. All significant findings remained; thus, the original analysis is reported below.

Infant attention

Do differences in caregivers' sensitivity/redirectiveness predict differences in infants' social looking preferences?

Figure 3a,b depicts the proportions of time that infants spent looking at different areas (looking categories; see Methods) while interacting with their caregivers. When caregivers were *not* engaged with objects (Figure 3a), infants of both HS and HR caregivers spent more than half of their time attending to objects on average (mean HS = 71.09% of looking time; mean HR = 75.68% looking time). Their next highest looking category was undirected areas (mean HS = 15.20% of looking time; mean HR = 14.35% of total looking time), followed by caregiver areas (mean HS = 13.71% of looking time; mean HR = 9.96% of total looking time). To determine whether infants of HS and HR caregivers differed in their looking preferences, and whether their preferences for objects were significant, we ran a 2 (caregiver group) × 2 (looking category: objects vs. undirected areas) mixed ANOVA on infants' proportions of looking time (Figure 3a). Because infants' looking categories are mutually exclusive and were assessed as relative proportions, we did not include the looking category that infants attended to the least (i.e., caregiver areas) in the analysis. This exclusion allows room for the summed proportions of the two looking categories included (objects and undirected areas) to vary such that the between-subjects term (caregiver group) can be assessed (for an example of a similar analysis strategy applied to proportions, see Deák et al., 2014). The 2 × 2 analysis revealed a significant main effect of looking category ($F(1, 15) = 108.93$, $p < .001$), with no main effect of caregiver group, and no looking category × caregiver group interaction.

When caregivers *were* manually engaged with objects, infants again appeared to spend over half of their time attending to objects on average (Figure 3b). To determine whether infants of HS and HR caregivers significantly preferred looking at *caregiver-engaged* objects over static objects during these periods, we ran a 2 (caregiver group) × 2 (object type: caregiver-engaged vs. static) mixed ANOVA. There was a significant main effect of object type (caregiver-engaged vs. static: $F(1, 15) = 10.995$, $p = .005$), with infants preferring to attend to caregiver-engaged objects over static objects. There was no significant main effect of caregiver group ($F(1, 15) = 0.998$, $p = .33$); however, there was a significant object type x group interaction ($F(1, 15) = 4.69$, $p = .047$). To explore this interaction further, we performed tests of simple main effects. These tests revealed that while infants of HS caregivers significantly preferred looking at caregiver-engaged over static objects ($F(1, 6) = 8.03$, $p = .030$), infants of HR caregivers showed no preference for looking at caregivers' held objects. Additionally, infants of HR caregivers spent a significantly greater proportion of time looking at static objects than infants of HS caregivers ($F(1, 15) = 8.01$, $p = .013$), although the two groups did not differ in their proportions of caregiver-engaged object looking.

Do differences in caregiver sensitivity/redirectiveness predict differences in infants' general attention span?

To investigate how caregiver sensitivity and redirectiveness affect infants' attention span, we ran a mixed-model 2 (caregiver group) × 2 (caregiver handling state: engaged vs. unengaged with objects) mixed ANOVA on infants' average rate of gaze shifting. We found a marginal main effect of caregiver group, as infants of HS caregivers shifted gaze marginally less frequently than infants of HR caregivers $F(1, 15) = 4.30$, $p = .056$; Figure 4). There was a significant main effect of caregiver handling state, as infants of both HS and HR caregivers appeared to shift more frequently when their caregivers were *not* manually engaged with objects ($F(1, 15) = 13.35$, $p = .002$). There was no significant interaction.

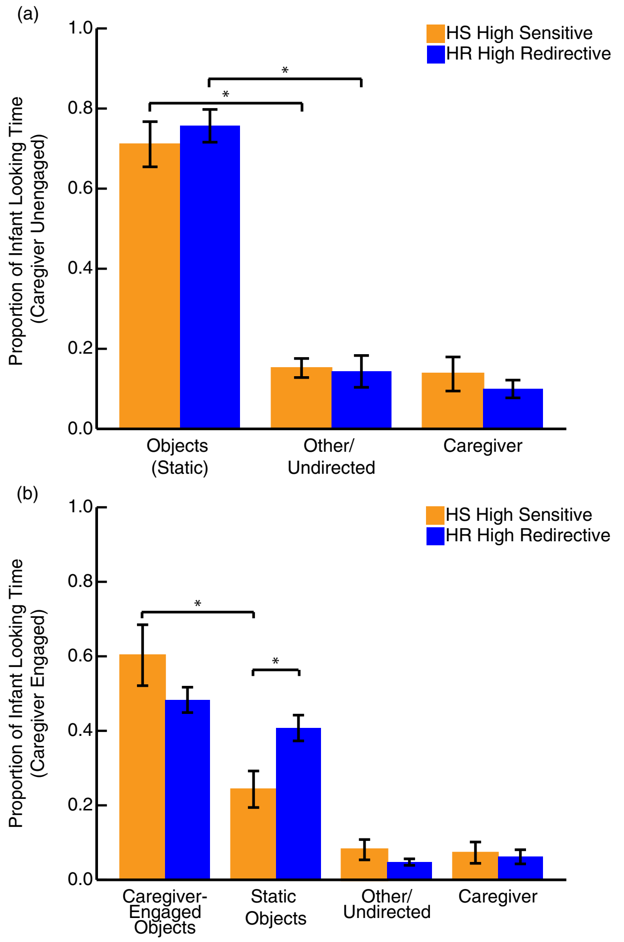

Figure 3 Infant looking times at relative areas of interest during social interactions with caregivers. Graphs show looking preferences of infants of HS and HR caregivers when (a) caregivers are not currently engaged with objects, and (b) caregivers are manually engaged with at least one object. Orange bars denote mean proportions of looking time for infants of highly sensitive caregivers; blue bars denote mean proportions for infants of highly redirective caregivers. *$p < .05$.

Do differences in caregiver sensitivity/redirectiveness predict differences in infants' attentional reactivity toward social cues specifically?

We next examined how frequently infants shifted gaze specifically in reaction to (i.e., within 2 sec of) their caregivers' contingent responses. First, to assess the direct effects of sensitive and redirective responses on infants' attentional reactivity, we compared across all dyads the proportions of responses that infants shifted to when the response was either sensitive or redirective.[2] Infants shifted gaze more frequently in

[2]Because two of the seven HS infants received 2 or fewer redirective responses each across the entire social interaction (and more generally, because the number of sensitive and redirective responses from which to sample differed robustly between HS and HR groups), a mixed-model comparison was unfeasible for this analysis.

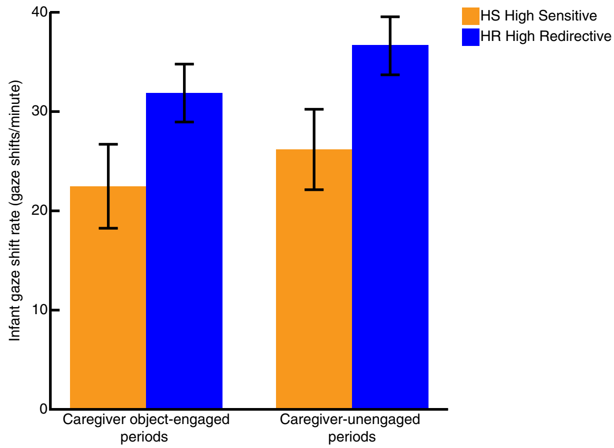

Figure 4 Overall gaze shifting rates for infants of HS and HR caregivers, during moments in which caregivers are engaged with objects and not engaged with objects. Orange bars denote mean rates for infants of highly sensitive caregivers; blue bars denote means for infants of highly redirective caregivers. There was a significant within-subjects main effect of caregivers' object handling on infants' shift rate, and a marginal between-subjects main effect (p = .056) of caregiver group.

reaction to redirective responses than to sensitive responses ($t(16) = -2.407$, $p = .029$; Figure 5). To examine HS and HR caregivers' redirection *success* independently, we next ran an exploratory analysis[3] quantifying the proportions of HS and HR caregivers' redirections that successfully caused infants to shift to the focus of the caregiver's attention. There were no significant between-groups differences in HS vs. HR caregivers' redirection success (HS success = 57.19% of all redirections, HR success = 49.80% of all redirections, $t(13) = .51$, $p = .62$). However, when exploring the specific latencies by which infants in both groups successfully followed caregivers' redirections, infants of highly sensitive caregivers more quickly followed their caregivers' redirective prompts than infants of HR caregivers (HS mean infant latency = .60 sec, HR mean = 1.05 sec, $t(13) = -3.27$, $p = .006$).

Next, we compared, between HS and HR caregivers, the total proportion of all contingent responses that elicited an infant attentional shift. Overall, infants of HR caregivers shifted gaze to a higher proportion of their caregivers' responses than infants of HS caregivers (mean HS = 52.35%, mean HR = 65.05%; $t(15) = -2.22$, $p = .04$; Figure 6). To examine the robustness of this effect, we next focused on infants' gaze shifting in reaction to *non-referentials* alone. Non-referential responses were exhibited at similar rates among both caregivers groups (HS mean rate of non-referential responses/minute: 3.07; HR mean: 3.41; $t(15) = -0.48$, $p = .64$) and were thus unbiased by our group assignment. As before, infants of HR caregivers shifted to a significantly higher proportion of non-referential behaviors compared to infants of HS caregivers (infants of HS caregivers: 51.72%; infants of HR caregivers: 66.35%; $t(15) = -2.24$, $p = .04$; Figure 6).

[3]To prevent binary proportion (0% or 100%) values for this analysis, we excluded dyads whose caregivers had provided <2 target-specific redirections.

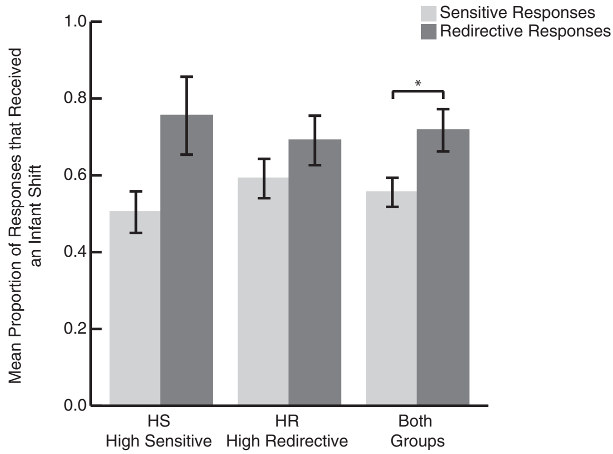

Figure 5 Graph depicting the effects of response type (either sensitive or redirective responses) on all infants' likelihood of shifting contingently to the response. Because the number of sensitive and redirective responses from which to sample differed robustly between HS and HR groups (for instance, two of the seven HS caregivers provided 2 or fewer redirective responses), we assessed the effects of sensitive and redirective responses across all dyads rather than between groups. Overall, infants were more likely to shift to a caregiver response when it was redirective compared to when it was sensitive. *$p < .05$.

Content of infant reactions. In addition to shift frequency, we also quantified the targets of focus that infants shifted to when they reacted to caregivers' responses (Table S3). Of these reactions, we were primarily interested in infants' shifts to non-referentials, given that such responses did not contain any information intended to direct infants' attention to a particular location. The targets of HS and HR infants' reactions to non-referentials are shown in Figure 7. When infants of highly sensitive caregivers shifted on non-referentials, 46.44% of these shifts were to objects on average, followed by undirected areas (35.12% of non-referential shifts) and infants' caregivers (18.44% of shifts). For infants of highly redirective caregivers, 71.46% of their non-referential shifts were to objects, followed by undirected areas (16.48% of shifts), and lastly to caregivers (12.05%). To assess whether infants of HS and HR caregivers showed a significant bias for shifting to objects over their next highest looking category (i.e., undirected areas), and whether any biases differed between groups, we ran a 2 (caregiver group) × 2 (looking category: objects vs. undirected areas) mixed ANOVA[4] on the proportion of infants' contingent shifts ending at either objects or undirected areas (Figure 7a). There was a significant main effect of looking category ($F(1, 15) = 33.77$, $p < .001$) as well as a significant looking category x caregiver group interaction ($F(1, 15) = 14.64$, $p = .002$), with no main effect of caregiver group ($F(1, 15) = 1.075$, $p = .32$). Tests of simple effects revealed that infants of HR caregivers showed a strong bias to shift to objects compared to undirected areas in response to non-referentials ($F(1, 9) = 76.15$, $p < .001$). Additionally, infants of HR caregivers

[4]Again, because the looking categories and their associated proportions are mutually exclusive, one looking category must be excluded in order to legitimize between-subjects comparisons among infants of HS and HR caregivers. Thus, for our analyses, we excluded the looking category that infants shifted to the least on average, that is, caregiver areas.

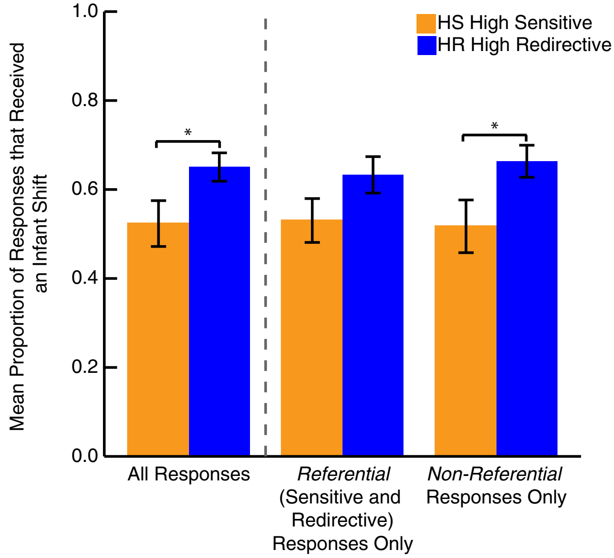

Figure 6 Graph depicting the proportions of caregiver responses that infants of highly sensitive (HS) and highly redirective (HR) caregivers shifted contingently in response to. The first group of columns illustrates infants' shifts towards all caregiver responses; the second group of columns depicts infants' shifts towards referential (sensitive or redirective) responses only; and the third group of columns illustrates infants' shifts towards non-referential responses only. $*p < .05$.

shifted to objects at a significantly higher frequency than infants of HS caregivers during these events ($F(1, 15) = 12.83$, $p = .003$). In contrast, infants of HS caregivers did not shift significantly more to objects over undirected areas in response to non-referentials ($F(1, 6) = 1.21$, $p = .31$). Furthermore, infants of HS caregivers showed a greater frequency of shifts to undirected areas during these moments compared to infants of HR caregivers ($F(1, 15) = 9.86$, $p = .007$).

To ensure that the differences observed in HS and HR infants' looking endpoints were not due to differences in what infants were attending to immediately prior to their caregivers' non-referential responses, we also examined the areas that infants were most recently attending to before receiving a non-referential response. Infants of both groups were most often attending to objects before receiving a non-referential response (mean HS = 64.21% of total occasions; mean HR = 73.91% of total occasions), and targeted comparisons revealed no significant between-groups differences in infants' attention to objects ($t(15) = -1.56$, $p = .14$) or to undirected areas (mean HS = 22.87%, mean HR = 9.71%; $t(15) = 1.97$, $p = .067$) prior to receiving a non-referential response.

DISCUSSION

We investigated how individual differences in social coordination among caregivers and their 5-month-old infants relate to differences in infants' early visual attention patterns. We focused on characteristics theorized to support the development of attention

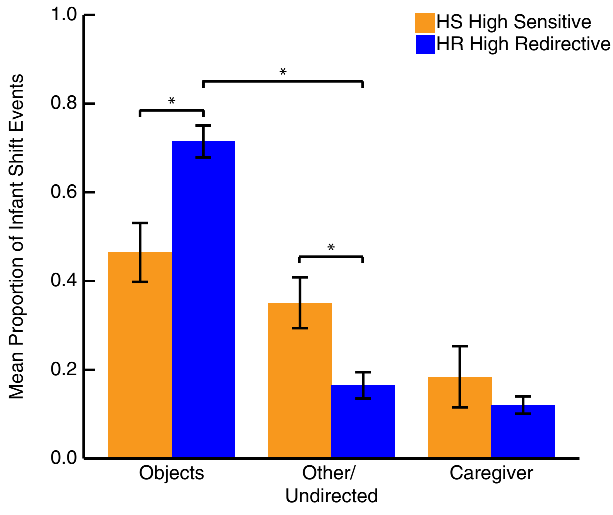

Figure 7 Visual targets of infant attentional reactions (shifts) in response to caregivers' non-referential responses. Orange bars denote mean proportions of shift events ending in each target for infants of highly sensitive caregivers; blue bars denote mean proportions for infants of highly redirective caregivers. *$p < .05$.

sharing and subsequent joint attention. Specifically, we assessed how opposing signal-to-noise ratios of contingent *sensitive* and *redirective* responding among caregivers correspond to differences in infants' attentional preferences toward socially relevant stimuli, as well as infants' general attention span and reactivity to caregivers' social prompts. Although all infants spent the majority of their time looking at objects, infants of highly sensitive caregivers showed attention patterns that imply social attunement (Kuchirko et al., 2018). This attunement was apparent within these infants' looking preferences as well as the timing of their gaze shifts, which accommodated the content of their caregivers' responses. These differences in early looking patterns may have implications for later attention sharing and joint attention in social contexts.

Regarding attentional focus, infants of highly sensitive caregivers significantly preferred attending to caregiver-held objects over other objects across the social interaction. In contrast, infants of highly redirective caregivers did not show a preference for objects with which their caregivers were engaged, attending relatively equally to static (non-caregiver related) objects. Furthermore, when caregivers responded with non-referential behavior, infants of highly redirective caregivers showed a more fixed pattern of shifting to unrelated objects, while infants of highly sensitive caregivers exhibited more distributed gaze toward objects and other areas. These results suggest that the attentional patterns of infants of highly sensitive caregivers are more strongly organized toward social partners and associated objects than are those of infants of highly redirective caregivers. Crucially, these differing patterns of attention organization held even when caregivers produced non-referential behavior.

Along with differences in infants' focus, we also found relations between caregivers' response patterns and infants' moment-by-moment social reactions. Namely, infants of highly sensitive caregivers exhibited some evidence of being more sensitive to the content of their caregivers' responses than infants of highly redirective caregivers. This was most apparent in the fact that infants of highly sensitive caregivers were less likely to shift gaze in reaction to caregivers' non-referential responses than infants of highly redirective caregivers. Non-referentials were similar in structure among both groups of caregivers (i.e., overwhelmingly verbal; Table S2) and, by definition, were not intended to support nor distract infants from their current focus. Thus, the fact that infants showed differences in shifting to these cues suggests that caregiver sensitivity and redirectiveness may also influence infants' reactivity toward more open-ended social behavior. Additionally, while HS and HR caregivers' redirections were equally likely to elicit a successful change in infants' focus, infants of highly sensitive caregivers were quicker to attend to their caregivers' occasional redirections than infants of highly redirective caregivers. This speed of attentiveness could in part be explained by these infants' overall sensitivity toward their caregivers' held objects (Figure 3b), as caregivers' redirections often involved manual/multimodal cues (Table S2). Another possibility is that infants of highly sensitive caregivers have learned that their caregivers' responses are most often aligned with infants' own focus and are thus more inclined to "infer" that their caregivers' occasional redirections will be predictive of something interesting as well. Whether or not HS caregivers' redirections are actually more predictive of infants' interests than those of HR caregivers remains to be determined. Nonetheless, our results taken together indicate that infants of highly sensitive caregivers may be more selectively attuned to their caregivers' social cues than infants of highly redirective caregivers. Such selectivity may be a precursor to the specificity of vocal, gestural, and affective responding that older infants exhibit during communicative exchanges with adults (e.g., Beebe et al., 2010; Kuchirko et al., 2018), though further longitudinal research is needed to explore this possibility further.

Until recently, studies of social attention development have often assessed infant looking in isolation, using highly controlled paradigms to investigate whether and when infants prefer to look at social stimuli (Johnson, Dziurawiec, Ellis, & Morton, 1991; Jones & Klin, 2013; Wilkinson, Paikan, Gredebäck, Rea, & Metta, 2014). Additionally, "social stimuli" have often been restricted to mean images of human faces and eyes (Johnson et al., 1991; Jones & Klin, 2013; Wilkinson et al., 2014; though see also Klin, Lin, Gorrindo, Ramsay, & Jonas, 2009). Newer work has expanded the notion of social stimuli, to include other sights and cues that are predictive of caregiver engagement in more naturalistic settings (Deák, Krasno, Jasso, & Triesch, 2018; Deák et al., 2013; Miller et al., 2009; Yu & Smith, 2013, 2016, 2017). Such work has shown that social attention may arise through multiple pathways, including through infants' attention to objects that their caregivers are holding or touching. The current study builds upon this line of research, to describe how individual differences in caregiver behavior might relate to differences in infants' levels of hand-object social attention. We found that only infants of highly sensitive caregivers preferred attending to their caregivers' held objects at 5 months of age. Although the question of causality remains open, our present findings may mean that high SSNRs of sensitivity strengthen hand-object pathways of joint attention development early on, which may in turn have implications for later communicative learning (e.g., Gogate, Bolzani, & Betancourt, 2006).

Current theories of joint attention development have also suggested that differences in physiological arousal and vigilance during infancy may contribute to differences in attention sharing. Specifically, heightened arousal presumably corresponds to increased gaze shifting (shorter look durations; de Barbaro, Clackson, & Wass, 2017) and less social cue following, as infants' attention is driven mainly by exploration of new sights and less by exploitation of predictable cues (Deák et al., 2013). In experimental settings, infants showing higher behavioral indices of arousal tend to shift more frequently and attend more to salient distractors over social cues (de Barbaro et al., 2011). Furthermore, shorter fixation durations in infants (an index of heightened arousal) have been associated with later characteristics of autism, including social-communicative difficulties (Wass et al., 2015; though see also Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004). In the present work, we found that while infants of highly redirective caregivers showed only a trend toward increased shifting overall, they were significantly more reactive to caregivers' non-attention-directing (non-referential) responses than infants of highly sensitive caregivers. Additionally, infants of highly redirective caregivers were slower to attend to caregivers' attention-directing prompts (redirections) than infants of highly sensitive caregivers. Thus, our findings lend partial support to the possibility that infants of highly redirective caregivers are exhibiting behavioral signs of hypervigilance relative to infants of highly sensitive caregivers and are partially in line with experimental work indicating that redirective adults cause infants to be more distractible (Miller et al., 2009). Further replications of our findings, presumably with a larger sample size, will be needed to further delineate relations between caregiver sensitivity/redirectiveness and infant arousal.

While our microstructural approach to assessing caregivers' behaviors and infants' attention patterns is a strength of the current study, some limitations should be noted. First, while our broader caregiver sample was of sufficient size for our initial observations of caregiver behavior, these caregivers exhibited a limited range of redirective behaviors (Figure 2), making it difficult to assess how marked SSNRs of redirective behavior relate to differences in our infant attentional measures. This limitation is likely a consequence of the homogeneity of our caregiver sample generally, the majority of whom were well educated, high social economic status (SES) families. Such homogeneity limits our ability to generalize our findings to more at-risk caregiver groups, including samples with lower SES. Additionally, the fact that even our most redirective caregivers often exhibited a high or "middle range" proportion of sensitive responses greatly restricted our sample size for infant attention analyses, given our interest in targeting infants of caregivers with highly contrasting SSNRs of sensitivity and redirectiveness. Future work should make efforts not only to explore the levels of redirectiveness and sensitivity observed in a broad range of caregiver groups from different backgrounds, but also to assess how these differing proportions of responsiveness might relate, on a more continuous level, to differences in infant attention.

Two types of data will be needed to further explore and expand upon our interpretation of our findings. First, we must compare the effects of SSNR with those of sensitivity and redirectiveness. In curiosity-driven learning (Oudeyer & Smith, 2016), the ability to predict outcomes and reduce uncertainty motivates infants to repeatedly engage with objects and stimuli surrounding them. Extending this idea to the social domain, both the timing and content of caregivers' responses may contribute varying levels of predictable structure to encourage infants' engagement. Sensitive responding may be associated with greater predictability, as caregivers' responses are controlled by the infant's own focus of attention. Sensitive responding may also reduce uncertainty regarding the objects that infants are currently exploring, as caregivers' engagement with these objects may provide more information about their affordances and properties. Such predictability may be the mechanism driving infants' attentiveness toward highly sensitive caregivers' social cues. However, infants' attentiveness might be further driven by the structure of caregivers' response timing. For instance, infants may more able to predict that their caregivers' social cues are reliably sensitive if caregivers are also highly contingent, that is, if they also respond promptly and frequently to infants' behaviors. Additionally, caregivers who are highly contingent and redirective may be more predictable (and thus perhaps more motivating) than caregivers who are highly redirective but who also do not respond reliably to infants' behaviors. As the caregivers in our targeted sample were fairly similar in their rates of contingent responsiveness, the present study did not differentiate between highly contingent and less contingent patterns of caregiver sensitivity and redirectiveness. However, experimental work in our laboratory is currently exploring how differing levels of contingency and of sensitivity/redirectiveness might interact to predict differences in infant looking, arousal, and motivation to attend to social cues. Follow-up work should also investigate how infants' preferences for predictable caregiver behavior changes over development and learning, if predictability is in fact found to be a primary factor underlying infants' social attention patterns.

Secondly, future work must address the issue of causality, and explore more intensively the bidirectional relations between caregiver responsiveness and infant attention differences. While differences in parental sensitivity and redirectiveness might create individual differences in social attunement, early differences in infants' patterns of attention might reciprocally shape how caregivers respond. For example, infants who have shorter attention spans early in development might prompt caregivers to redirect their attention more frequently. In turn, more redirections could cause increased gaze shifting and arousal, which would also influence infants' attention to social cues. Alternatively, longer looking during infancy might provide caregivers with more opportunities to provide sensitive feedback. Sensitive responding in turn could encourage sustained attention as well as attention to caregivers' subsequent social cues. Current research in our laboratory is working to tease apart the question of causality by examining short-term effects of experimenter-controlled sensitivity and redirectiveness on infant attention in social interactions. Additionally, future longitudinal analyses in our laboratory will examine how caregivers' response structures change over development (Bornstein et al., 2008), and whether such changes correspond to differences in infant attention as well as later social and communicative outcomes.

We hope that the current study will provide a first step in connecting individual differences in dyadic coordination with differences in early infant visual patterns associated with later attention sharing. While further investigation and replication with larger samples is necessary, our findings indicate that differences in contingent sensitivity and redirectiveness relate to infant attention differences in social contexts as early as 5 months of age. Such differences in early attention patterns, as well as in predictive learning, are increasingly recognized as key components of neurodevelopmental conditions (Sinha et al., 2014). We thus anticipate that our observations may be combined with future work to inform our knowledge of the specific social structures important for attention development, as well as interventions aimed at improving overall attention and attention sharing among at-risk infants and children.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Figure S1. Relations between caregiver sensitive and redirective response types, and caregiver non-referential responses for entire caregiver sample ($N = 67$).

Table S1. Interrater Reliability Statistics for Individual Infant and Caregiver Variables

Table S2. Modality Characteristics of Sensitive, Redirective, Non-referential, and All Contingent Responses Provided by Highly Sensitive (HS) and Highly Redirective (HR) Caregivers

Table S3. Composition of Infant Shift Types in Reaction to Caregivers' Contingent Sensitive, Redirective, and Non-referential Responses